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Americans cultivate a large and diverse range of introduced woody plants as important sources of food and forest products, as well as for urban horticulture, amenity and wildlife plantings, and windbreaks. A small number of these species have become serious pests, disrupting well-established native plant communities or functioning as range and agricultural weeds. More of these species are not serious pests today, but have escaped cultivation and serve as potential sources of future outbreaks. Two other sources of potentially invasive woody plants are found among species that are not or are only rarely cultivated, about which we often know little regarding their adaptation and reproductive biology, and among new populations of well-known taxa, superior in invasive ability to populations already extant. Methods have been developed to evaluate the invasive potential of woody plants in North America, resulting from detailed analyses of life history, biosystematics, phytogeography, and known records of invasions in other parts of the world. Because these methods were developed to make predictions on a continental scale, they cannot account for differences in environmental adaptations that woody plants have evolved in their natural habitats. The present study reviews the use of environmental analogs in predicting woody plant adaptation. The native ranges of 28 non-native, woody taxa known to be invasive in Iowa are then mapped and compared with the geographic occurrence of environmental analogs to Iowa growing conditions, based on January mean temperature, moisture balance, and latitude, three limiting factors influencing woody plant survival in the north central United States. Regions with the highest number of native taxa among the 28 taxa mapped are found in southeastern Europe and northeastern China. Climatic analogs to Iowa conditions are found in Ukraine, Romania, Turkey, Armenia, Georgia, Kazakhstan, China, North Korea, and the Russian Far East. Climatic analogs in Ukraine, Romania, and China overlap with those regions containing the highest number of invasive woody plants. These regions of overlap are also within the native ranges of nine woody taxa that are potentially invasive in Iowa. This information should be valuable for conducting a geographic risk analysis to refine existing methods for evaluating the invasive potential of non-native woody plants in Iowa and surrounding areas.

INDEX DESCRIPTORS: climatic analog, distribution, range, geographic analysis, risk analysis, tree, shrub, invasive exotic plant.

Prologue

"Studies that consider the biological and ecological characteristics of the alien species, and the attributes of both the native habitat and the habitat to which it will be or is introduced, may in time come to achieve a high degree of predictive success. However, the huge volume of species introductions (many accidental and unrecorded) to so many places precludes the possibility of detailed studies for all aliens. Nevertheless, in environmentally sensitive areas the stakes are high enough to investigate thoroughly those species which pose potential threats" (Cronk and Fuller, 1995, p. 34).

In the United States, we rely upon a large and diverse range of introduced tree, shrub, and vine species as important sources of food and forest products, as well as for urban horticulture, amenity and wildlife plantings, and windbreaks. A small proportion of these species have become serious pests, disrupting well-established native plant communities or functioning as range and agricultural weeds. A larger proportion of these species are not serious pests today, but have escaped cultivation and serve as a potential source of future invasive exotics, a pattern consistent with data assembled for plants in many parts of the world (Williamson 1993, Kowarik 1995, Lippincott 1996, Parker and Reichard 1998). There are two other important sources of potentially invasive woody plants worthy of attention. The first group consists of those species that are not or are only rarely cultivated, for which we may know little about their range of adaptation and reproductive biology. The second includes new populations of well-known taxa, which are superior in invasive ability to populations already present in the United States.

Reichard and Hamilton (1997) published criteria and decision trees to help evaluate the invasive potential of woody plants in North America. Their criteria resulted from detailed analyses of life-history characteristics, biosystematics, phytogeography, and known histories of invasions in other parts of the world. Their criteria may prove to be extremely useful tools, but by attempting to develop criteria that apply on a continental basis, Reichard and Hamilton (1997) were unable to include in their models some important characteristics about relationships between woody plants and the environments in which they have evolved and indicated that analysis of geographic origin "may be most useful in regional models."

Thus, for specific regions, it may be possible to build more robust criteria by including information about environmental conditions crucial in shaping the evolution of woody plants in their native habitats. Such approaches have proven useful in assessing potential weeds in Australia and New Zealand (Panetta and Mitchell 1991a and 1991b, Panetta 1993, Scott and Panetta 1993). The present study focuses on the comparison of climatic and other environmental conditions as applied to the identification of potentially invasive woody plants in Iowa.

It should not be surprising that modeling based on climatic variables, long useful in predicting distribution of plant communities (Mather and Yoshioka 1968, Greller 1980, Looman 1983, Sowell 1985, Woodward and Williams 1987, Stephenson 1990), could also elucidate the natural ranges of individual woody plant species. Trees

and shrubs, with their extended juvenility, overall longevity, and substantial aboveground biomass, are subjected to long-term climatic extremes and fluctuations that may be avoided or escaped by herbaceous plants. These characteristics should result in the evolution of woody plants that are well adapted to specific environmental regimens and that may also thrive under similar conditions outside of their native distributions.

The roles of extreme low temperatures and lack of sufficient summer heat in limiting the northern distribution of woody plants have been extensively researched (George et al. 1974, Skre 1979, Pigott and Huntley 1981, Quamme et al. 1982). Shao and Halpin (1995) developed predictive models of the distributions of six tree and shrub species native to the southeastern United States based on moisture balance and growing degree day data. And recently, Thompson et al. (2000) published analyses of the native ranges of more than 300 North American trees and shrubs in relation to parameters measuring temperature, precipitation, and moisture balance, and presented detailed examinations of how these environmental parameters relate to the natural distributions of nine *Pinus* species.

Beyond analysis of the environmental factors that influence the native ranges of woody plants, comparative climatic analysis has also been useful in predicting the survival and performance of woody plants in horticultural and forestry trials, based on climatic data from both the locations of the trial sites and original collection sites. A project to select for cold hardiness among populations of an ornamental shrub, *Leptospermum scoparium* J.R. & G. Forst., native to New Zealand demonstrated how climatic data from collection sites could predict plant performance in France (Decourtye et al. 1991, Harris and Decourtye 1991, Decourtye and Harris 1992). This project later demonstrated similar differences among populations of other introductions from New Zealand (Harris and Decourtye 1995). In addition, sophisticated multivariate climatic modeling has proven useful in predicting the performance of forest trees in China (reviewed in Booth 1999), Australia, and New Zealand (Battaglia and Sands 1997, Coops et al. 1998).

In the north central United States, the results of two long-term studies have been used to analyze the roles climatic variables play in explaining regional variation in survival for wide arrays of woody plants introduced from the former nation of Yugoslavia (Widrlechner et al. 1992) and from northern Japan (Widrlechner et al. 1998). Fairly simple, multiple-regression models, explaining substantial proportions of geographic variation for plant survival, resulted from these two studies. For Yugoslav plants, survival was a function of January mean temperature and moisture balance. For Japanese plants, survival was a function of moisture balance and two interaction factors involving moisture balance along with January and July mean temperatures.

A recent paper by Leege and Murphy (2000) presented an unexpected opportunity to test a regression model resulting from the Yugoslav study in a way that helps determine its utility in predicting the survival of an invasive species. Thousands of seedlings of *Pinus nigra* J. F. Arnold subsp. *austriaca* (Hoess) Badoux, native to Austria, Slovenia, and western Croatia, were planted on sand dunes in Allegan County, Michigan and are now naturally regenerating. Plant survival of 16 to 32-year-old trees on the site was reported to be approximately 80%. When climatic variables for January mean temperature and moisture balance in Allegan County were applied to the "Yugoslav" model, it resulted in an estimate of overall survival of 71%. Based on specific results from the evaluation of *P. nigra* (Widrlechner et al. 1992), which indicated that this species was in the "hardiest" one-third of the cohort of species tested, although the model was based on mean performance over all taxa tested, it is likely that the model would underestimate survival for *P. nigra*.

Given the potential value of climatic variables in explaining both natural, woody-plant distribution patterns and the adaptation and performance of woody plants in cultivation outside their native ranges, the present study compares the native ranges of exotic woody plants known to have naturalized in Iowa with geographic regions based on climatic resemblance to Iowa conditions for clearly defined parameters. Herein these regions are referred to as climatic analogs, in the sense of Widrlechner (1994). The results of these comparisons are then used in an attempt to determine which parts of the world are most likely to have environmental conditions that can result in climatic adaptation to Iowa conditions and increase the risk of invasiveness of woody plants introduced from such locations.

Table 1. Core list of non-native woody plants naturalized in the flora of Iowa (Taxonomy follows the Germplasm Resources Information Network database for the National Plant Germplasm System [Wiersema 1995, National Germplasm Resources Laboratory—Data Management Unit 2000] (http://www.ars-grin.gov/npgs)).

Acer tatarica L. subsp. *ginnala* (Maxim.) Wesm.
Ailanthus altissima (Mill.) Swingle
Berberis thunbergii DC
Campsis radicans (L.) Seem ex Bureau
Catalpa speciosa (Warder ex Barney) Warder ex Engelm.
Elaeagnus angustifolia L.
Elaeagnus umbellata Thunb.
Euonymus alatus (Thunb.) Siebold
Lonicera maackii (Rupr.) Maxim.
Lonicera tatarica L.
Lycium barbarum L.
Maclura pomifera (Raf.) C.K. Schneid.
Malus sylvestris Mill.
Morus alba L.
Populus alba L.
Prunus tomentosa Thunb.
Rhamnus cathartica L.
Robinia pseudoacacia L.
Rosa multiflora Thunb.
Rosa rubinigosa L.
Rubus parvifolius L.
Salix alba L.
Salix fragilis L.
Salix × *rubens* Schrank
Sorbus aucuparia L.
Ulmus pumila L.
Viburnum opulus L. var. *opulus*
Viburnum lantana L.

METHODS

An initial list of non-native, woody taxa with evidence of naturalization in Iowa (see Table 1 in Farrar 2001) or potential to become naturalized was developed by reviewing florisitic treatments by Eilers and Roosa (1994) and Swink and Wilhelm (1994), consultation with Dr. Donald Farrar, personal participation in the Flora of Ames project (Norris et al. 2001), and 16 years of field experience botanizing in Iowa and surrounding states. The list was then refined into a core list (Table 1) by excluding those taxa that are rarely found in Iowa or only persist vegetatively after cultivation and three taxa that are interspecific hybrids between native and non-native taxa: *Morus alba* L. × *M. rubra* L., *Populus alba* L. × *P. grandidentata* Michx., and *Ulmus pumila* L. × *U. rubra* Muhl. A second list of taxa that are invasive in surrounding states, but have not yet widely escaped in

Table 2. Potentially invasive taxa, including native range and current status in Iowa.

Taxon	Native Range and Current Status
Alnus glutinosa (L.) Gaertn.	Europe, N Africa, and W Asia: only record in Furlow (1997)
Ampelopsis brevipedunculata (Maxim.) Trautv.	NE Asia: rare escape (Norris et al. 2001)
Celastrus orbiculatus Thunb.	NE Asia: rare escape (Eilers and Roosa 1994)
Euonymus europaeus L.	Europe and W Asia: no published records, observed by author in IL
Euonymus fortunei (Turcz.) Hand.-Mazz.	NE Asia: no known records, observed by author in MO
Ligustrum obtusifolium Siebold & Zucc.	NE Asia: rare escape (Norris et al. 2001)
Ligustrum vulgare L.	Europe, N Africa and W Asia: rare escape (Norris et al. 2001)
Lonicera japonica Thunb.	NE Asia: only record in Wilson (1992)
Rhamnus frangula Mill.	Europe, N Africa and W & C Asia: rare escape (Eilers and Roosa 1994)

Iowa (Table 2), was also developed to see if those taxa might be predicted to be invasive based on geographic and climatic analyses.

Native ranges for species listed in Tables 1 and 2 were obtained from the Germplasm Resources Information Network database for the National Plant Germplasm System (National Germplasm Resources Laboratory—Database Management Unit 2000) ⟨http://www.ars-grin.gov/npgs⟩ and refined with distributional data from Deam (1940), Gould (1962), Steyermark (1963), Tutin et al. (1964–1980), Ohwi (1965), Little (1971), Long and Lakela (1971), Li et al. (1977), Strausbaugh and Core (1978), Wherry et al. (1979), Wunderlin (1982), Naruhashi (1987), Gleason and Cronquist (1991), Cooperrider (1995), Fang et al. (1999), and Thompson et al. (2000). A composite map of the native distributions of the 28 taxa listed in Table 1 was then prepared (Fig. 1).

An analysis of world climatic analogs to Iowa, based on three factors known to be significant to the adaptation of woody plants in the north central United States (Widrlechner 1992, Widrlechner et al. 1992, 1998), January mean temperature, moisture balance, as measured by Mather and Yoshioka's (1968) moisture index, MI, where MI = 1 − ((annual precipitation ÷ potential evapotranspiration) × 100), and photoperiod regimen (as manifest through latitudinal differences), was then performed. Data on January mean temperature and annual precipitation were obtained from the National Climatic Data Center's temperature data for the period 1961–1990, as accessed via the High Plains Regional Climate Center (2000) ⟨http://www.hpccsun.unl.edu⟩ and the Midwestern Regional Climate Center (2000) ⟨http://mcc.sws.uiuc.edu⟩, as well as from Sapozhnikova (1964), Atlas SSSR (1969), Steinhauser (1970, 1979), Hoffman (1975), Institul de Geographie (1979), Voikov Main Geophysical Observatory (1981), and China Meteorological Administration (1994). Additional data to estimate the moisture balance were obtained from Sapozhnikova (1964), Thran and Brockhuizen (1965), Carter and Mather (1966), China Meteorological Administration (1994), and Widrlechner (1999).

RESULTS AND DISCUSSION

Composite Distributions

The composite distribution of the 28 non-native, woody taxa (Table 1) known to have naturalized in Iowa (Fig. 1) displays certain geographic patterns worthy of discussion. Of these 28 taxa, 4 are native to the southeastern United States, and the other 24 are primarily native to Eurasia, with outlying populations in North Africa and Australia.

The four species native to the southeastern United States have been widely cultivated in Iowa for both ornamental (*Campsis* and *Catalpa*) and forestry/conservation (*Maclura* and *Robinia*) purposes (van der Linden and Farrar 1984). In Iowa, both *Campsis* and *Maclura* can suffer low-temperature injury in particularly cold winters, but this does not seem to have limited their reproduction, especially in the southern part of the state. Given the postglacial history of Iowa (Prior 1991), it may be that these taxa had not yet reached the northern limits of their natural distributions at the time of European settlement and that cultivation hastened their northern spread.

The larger group of non-native invasive species are found in Eurasia, with two main zones of concentration. The larger zone stretches from western China, west through Kazakhstan and southern Russia, to northern Turkey and much of western Europe. Only in the west does this zone represent a forested continuum; from southeastern Ukraine to western China, there are many forested islands embedded in grassland and desert habitats. Within that zone, the highest concentration of taxa (10) is found in a region including parts of Belarus, Ukraine, Romania, the former Yugoslavia, Albania, Austria, and Germany. A smaller zone stretches from northeastern China, east through Korea, to Honshu in Japan. Within that zone, the highest concentration of taxa (10–11) is found in Hebei and Liaoning Provinces in northeastern China.

Of the 24 taxa native to Eurasia, 10 are found in the zone of highest concentration in southeastern Europe, and a different set of 11 is found in the zone of highest concentration in northeastern China. The three remaining taxa are native outside of these two geographic foci: *Ailanthus* is native to southern China, *Berberis* to Japan, and *Lonicera tatarica* to central Asia.

Climatic Analogs

An evaluation of temperature and moisture conditions was conducted through latitudinal zones worldwide bounded between 35 and 50°N and 35 and 50°S latitude, reflecting the adaptation of woody plants to photoperiod regimens resembling conditions in Iowa. The interwoven relationships among plant growth, climatic adaptation, and photoperiod regimen for woody plants are reviewed by Widrlechner (1994).

Regions within those latitudinal zones that typically experience January mean temperatures between −5 and −10°C, along with a moderate, positive moisture balance (corresponding to a moisture index between approximately 0 and 35), were then mapped. These regions are analogous to conditions in Iowa for two important climatic variables that are closely related to woody plant survival (Widrlechner et al. 1992, 1998).

There are five general regions meeting these simple criteria. The largest region (Fig. 2) includes most of Iowa and parts of Missouri, Nebraska, South Dakota, Wyoming, Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, and Ontario. The remaining four regions are found in Eurasia (Fig. 3). The second largest region includes much of North Korea and parts of Liaoning Province in China and the extreme southern tip of the Russian Far East. The next largest regions include two sites located in the foothills of the Carpathian

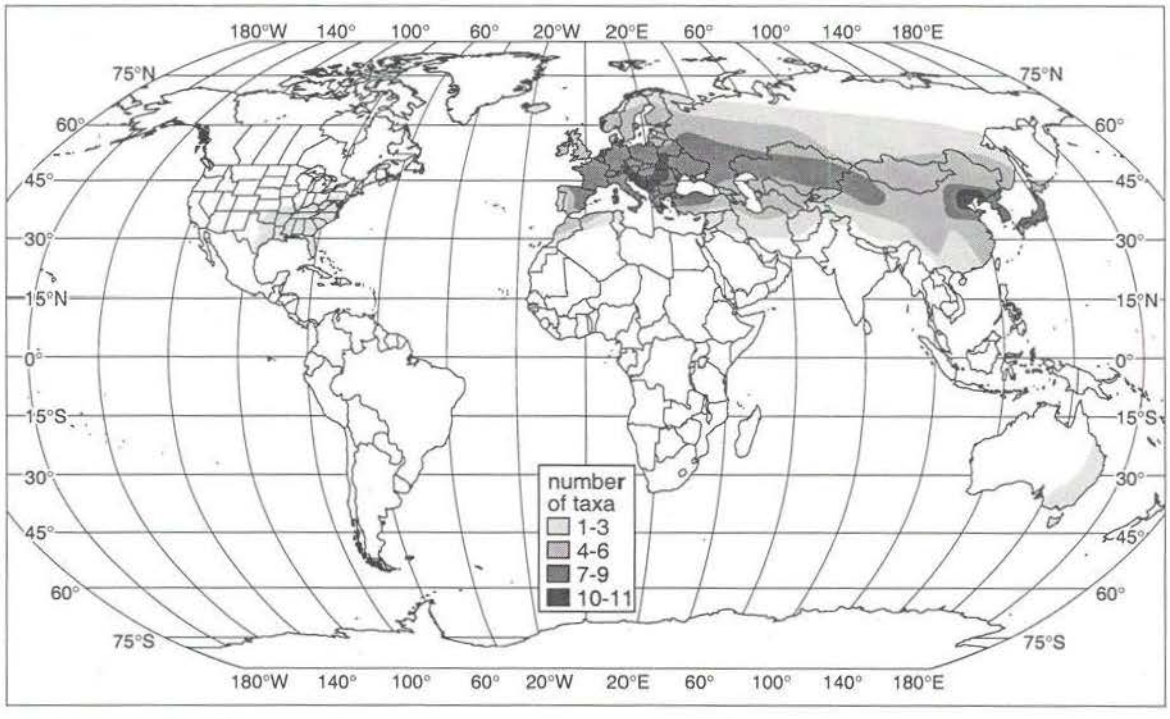

Fig. 1. Composite distribution of 28 non-native, woody taxa known to be naturalized in Iowa.

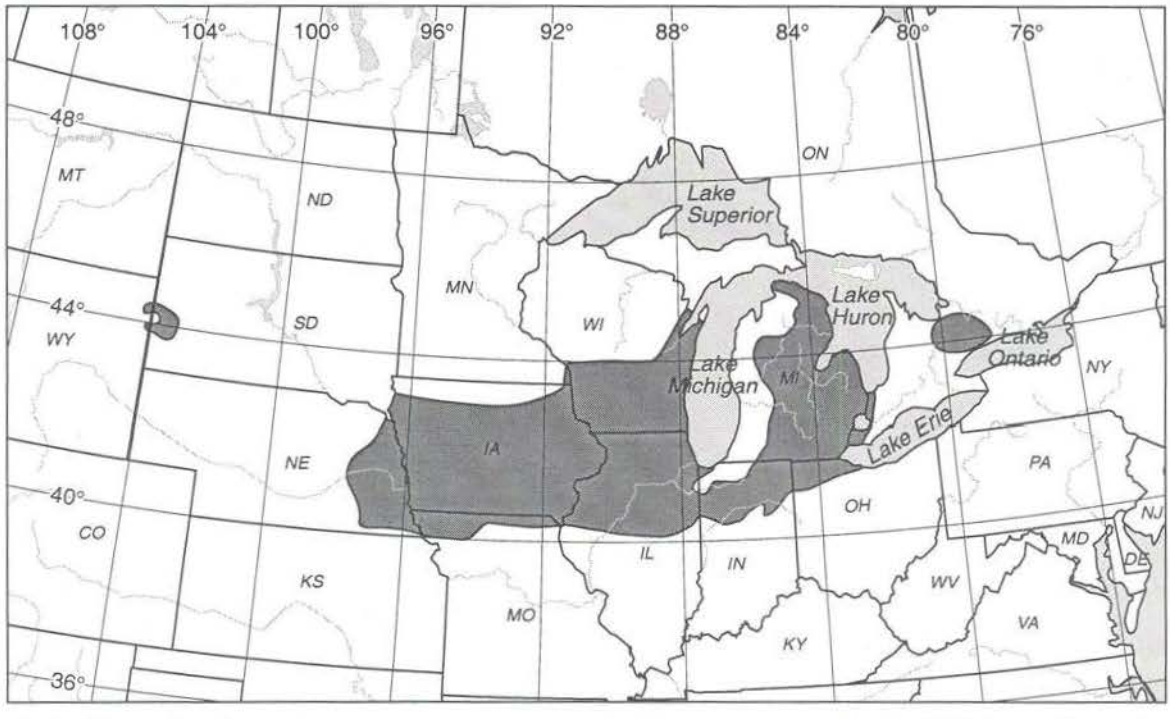

Fig. 2. North American regions that typically experience January mean temperatures between −5 and −10°C, along with a moderate, positive moisture balance (corresponding to a moisture index between approximately 0 and 35).

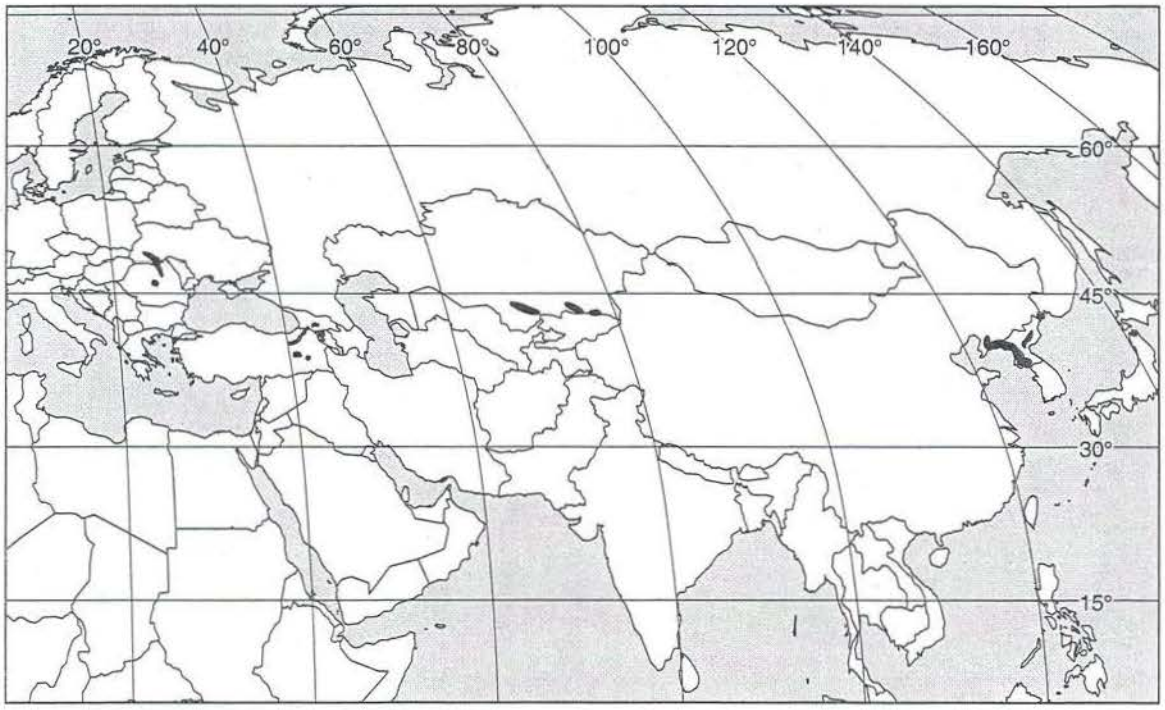

Fig. 3. Eurasian regions that typically experience January mean temperatures between −5 and −10°C, along with a moderate, positive moisture balance (corresponding to a moisture index between approximately 0 and 35).

Mountains in Ukraine and Romania and eight small sites in eastern Turkey, Armenia, and Georgia. There are also three small sites in the mountains of southern Kazakhstan. Finally, there may be some very small areas in the Andes Mountains along the border between Argentina and Chile near 36°S latitude, but the transition between desert and relatively moist, montane climates is extremely abrupt in this nearly unpopulated area, hampering the precise identification of analogs; thus they are unmapped.

Comparison of Composite Distributions and Climatic Analogs

The two main zones of concentration in species distribution in Eurasia (Fig. 1) include many parts of the world with climatic conditions quite unlike Iowa, ranging from Mediterranean and desert climates to regions of extremely high moisture surpluses, but this is expected because of the wide ranges that most of the 24 Eurasian species exhibit. Only three of the taxa, *Ailanthus, Berberis,* and *Lycium,* are endemic to regions that do not include at least one of the identified climatic analogs. Notably, the latitudinal ranges of two main zones of concentration in the native ranges of naturalized taxa generally lie between 35 and 55°N latitude, supporting the use of a latitudinal criterion in identifying climatic analogs.

Of the four regions of climatic analogs in Eurasia, the largest (in northeastern Asia) overlaps with the region of highest concentration of naturalized taxa in Liaoning Province (Fig. 4a). The climatic analogs of Ukraine and Romania are completely included within the European region of highest concentration (Fig. 4b). And the climatic analogs of Kazakhstan are located at the southern edge of the main zone of concentration stretching across central Asia. However, the climatic analogs of Turkey, Armenia, and Georgia are somewhat less congruent with the composite distributions (Fig. 4b), occurring both along the southern edge of the main zone of concentration and in a zone of lower density. This may be related to the fact that, unlike the previous three regions, these climatic analogs have precipitation maxima in winter and/or spring (Steinhauser 1970) rather than summer maxima, as found in Iowa.

Nine Potentially Invasive Taxa

The native ranges of nine taxa known to be invasive in states surrounding Iowa (Table 2), but not yet problematic in Iowa, were compared with the composite distribution map (Fig. 1) and with the locations of climatic analogs (Figs. 2 and 3). Five of these nine taxa have native ranges that include the zone of highest concentration in northeastern Asia, and the other four are found in the zone of highest concentration in southeastern Europe (Table 2). The five taxa native to northeastern Asia are also native to the region of analogous climate, and the four taxa native to Europe are native to both the climatic analogs in Ukraine and Romania and those in Turkey, Armenia, and Georgia. Of these nine taxa, only two, *Alnus glutinosa* and *Rhamnus frangula,* are native to Kazakhstan.

Thus, both the composite distribution and climatic analogs are valuable in predicting that these taxa are potential threats. It remains to be seen which of these nine species, which today are primarily found in states to the south and east of Iowa, are experiencing climatic or other environmental limits to range expansion to the north and west, or if it is only a matter of time before they spread into Iowa. The dynamics of these species' distributions should be documented carefully, and it may be useful to alert land managers in Iowa of the possible problems they may cause.

Conclusion and Future Directions

Past evaluation of woody plants in the north central United States indicated that low winter temperatures, drought, and photoperiod regimen all can limit the survival of non-native, woody plants in Iowa and surrounding states. The overlap of the zones of highest concentration of 28 woody taxa known to naturalize in Iowa with

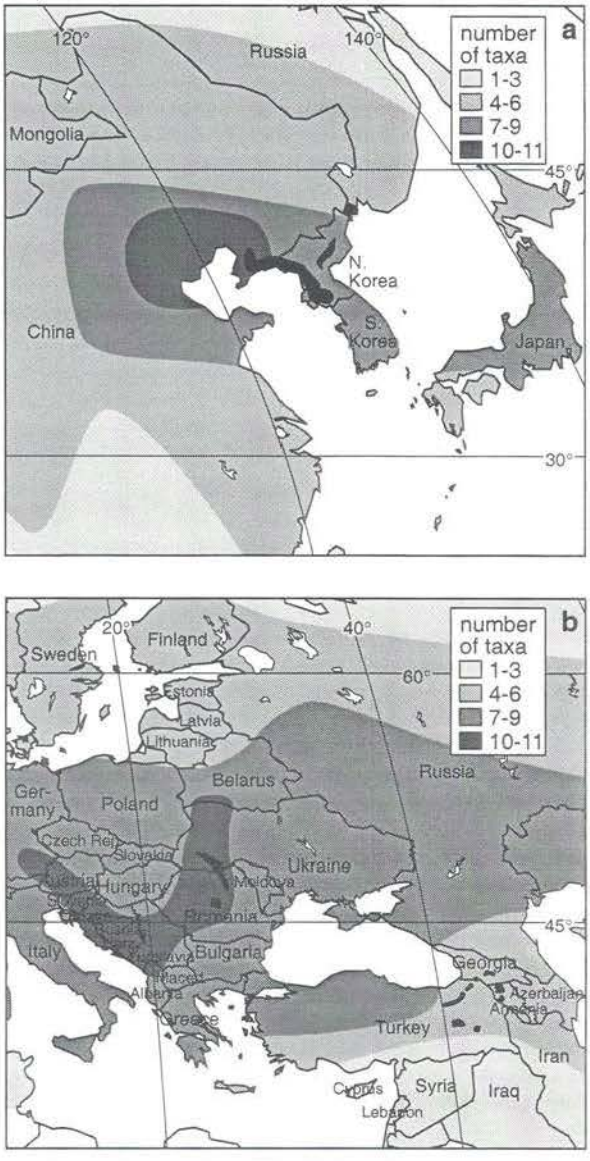

Fig. 4. Relationships between zones of highest numbers of non-native, naturalized taxa and climatic analogs: a) northeastern Asia; b) southeastern Europe. Climatic analogs are indicated with black shading.

two regions of analogous climate help validate the use of climatic analogs as a predictive tool. This is also supported through range analysis of nine potentially invasive taxa. It would be worthwhile to test the approach of examining the natural ranges of known invasives (as well as those species not showing invasive tendencies) in relation to climatic and other limiting environmental factors to determine whether this model has broader utility for non-native woody plants in other parts of the United States. Another related topic of investigation that deserves attention is the study of the overall outcomes of past woody plant introductions to the United States from regions of analogous climate.

Decision trees, such as the one developed by Reichard and Hamilton (1997) for North America, could then be refined for specific regions by including risk assessments of provenance based on a combined analysis of environment and the natural ranges of taxa already known to be invasive (along with an examination of the natural ranges of taxa with long histories of cultivation but no evidence of invasiveness) in concert with a regional reanalysis of the life-history characteristics of invasive woody plants. Although many life-history characteristics, such as avian seed dispersal, are likely to be important determinants of invasiveness throughout North America, other attributes, typical of invasive taxa on a continental scale, may be maladapted in regions that are climatically harsher than average or that have historically supported non-woody vegetation, such as the prairies of Iowa and surrounding states.

A matrix combining Reichard and Hamilton's three categories of "admission status" (accept, reject, and further analysis/monitoring needed) with risk categories based on the provenance of the plant population in question should lead to more accurate predictions. The appropriate classification of geographic regions into categories based on risk would thus be a timely subject for research. Through such efforts, we can help accomplish Cronk and Fuller's (1995) goal of developing models that achieve a high degree of predictive success.

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LITERATURE CITED

ATLAS SSSR. 1969. Atlas SSSR. Glavnoe upravlenie geodezii i kartografii pri Sovete Ministrov SSSR, Moscow.

BATTAGLIA, M., and P. SANDS. 1997. Modelling site productivity of *Eucalyptus globulus* in response to climatic and site factors. Australian Journal of Plant Physiology 24: 831–850.

BOOTH, T. H. 1999 Matching germplasm to geography: environmental analysis for plant introduction. Pages 63–74. *In* Linking genetic resources and geography: Emerging strategies for conserving and using crop biodiversity. S. L. Greene and L. Guarino (eds.). CSSA Special Publication 27. American Society of Agronomy and Crop Science Society of America, Madison, Wisconsin.

CARTER, D. B., and J. R. MATHER. 1966. Climatic classification for environmental biology. C. W. Thornthwaite Associates Publications in Climatology 19: 305–395.

CHINA METEOROLOGICAL ADMINISTRATION (eds.) 1994. Zhongguo qihou ziyuan dituji. (Atlas of the climate resources of China.) China Atlas Press, Beijing.

COOPERRIDER, T. S. 1995. The Dicotyledonae of Ohio. Part 2. Linaceae through Campanulaceae. The Ohio State University Press, Columbus.

COOPS, N. C., R. H. WARING, and J. J. LANDSBERG. 1998. Assessing forest productivity in Australia and New Zealand using a physiologically-based model driven with averaged monthly weather data and satellite-derived estimates of canopy photosynthetic capacity. Forest Ecology & Management 104: 113–127.

CRONK, Q. C. B., and J. L. FULLER. 1995. Plant invaders—the threat to natural ecosystems. Chapman & Hall, London.

DEAM, C. C. 1940. Flora of Indiana. Indiana Department of Conservation, Indianapolis.

DECOURTYE, L., W. HARRIS, and A. CADIC. 1991. Collecte et évaluation d'arbustes ornementaux spontanés en Nouvelle-Zéland et au Népal. Comptes Rendus de l'Académie d'Agriculture de France 77: 75–88.

DECOURTYE, L., and W. HARRIS. 1992. Selection for cold resistance in

Leptospermum scoparium (J.R. et G. Forst.). Acta Horticulturae 320: 39–48.

EILERS, L. J., and D. M. ROOSA. 1994. The vascular plants of Iowa: An annotated checklist and natural history. University of Iowa Press, Iowa City.

FANG, Z., S. ZHAO, and A. K. SKVORTSOV. 1999. Salicaceae. Pages 139–274. *In* Flora of China. Volume 4. Missouri Bot. Garden, St. Louis, and Science Press, Beijing.

FARRAR, D. F. 2001. Exotic and invasive woody plant species in Iowa. Journal of the Iowa Academy of Science 108:xxx–xxx.

FURLOW, J. J. 1997. Betulaceae. Pages 507–538. *In* Flora of North America north of Mexico. Volume 3. Magnoliophyta: Magnoliidae and Hamamelidae. Oxford University Press, New York.

GEORGE, M. F., M. J. BURKE, H. M. PELLETT, and A. G. JOHNSON. 1974. Low temperature exotherms and woody plant distribution. HortScience 9: 519–522.

GLEASON, H. A., and A. CRONQUIST. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd ed. New York Botanical Garden, Bronx.

GOULD, F. W. 1962. Texas plants—a checklist and ecological summary. Texas A&M Press, College Station.

GRELLER, A. M. 1980. Correlation of some climatic statistics with distribution of broadleaved forest zones in Florida, U.S.A. Bulletin of the Torrey Botanical Club 107: 189–219.

HARRIS, W., and L. DECOURTYE. 1991. Winter climatic comparison between France and New Zealand: effects of frost damage on populations of *Leptospermum scoparium* JR et G Forst grown at three locations in France. Agronomie 11: 847–861.

HARRIS, W., and L. DECOURTYE. 1995. Observations on cold damage to New Zealand plants grown at Angers, France. Horticulture in New Zealand 6: 9–19.

HIGH PLAINS REGIONAL CLIMATE CENTER. 2000. Historical data summaries. Internet URL: ⟨http://www.hpccsun.unl.edu/products.html⟩.

HOFFMAN, J. A. J. (ed.) 1975. Climatic atlas of South America. Volume 1. Maps of mean temperature and precipitation. WMO, UNESCO, Geneva. 28 maps.

INSTITUL DE GEOGRAPHIE. 1979. Atlas Republicii Socialistă România. Editura Academiei Republicii Socialiste România, Bucharest.

KOWARIK, I. 1995. Time lags in biological invasions with regard to the success and failure of alien species. Pages 15–38. *In* Plant invasions—general aspects and special problems. P. Pyšek, K. Prach, M. Rejmánek, and M. Wade (eds.). SPB Academic, Amsterdam.

LEEGE, L. M., and P. G. MURPHY. 2000. Growth of the non-native *Pinus nigra* in four habitats on the sand dunes of Lake Michigan. Forest Ecology & Management 126: 191–200.

LI, H.-L., T.-S. LIU, T.-C. HUANG, T. KOYAMA, and C. E. DEVOL. (eds.) 1977. Flora of Taiwan, Volume 3. Epoch Publ., Taipei.

LIPPINCOTT, C. 1996. Estimates of cultivated, native, naturalized, and weedy plant species in Florida. Palmetto 16(2): 12.

LITTLE, JR., E. L. 1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. USDA Forest Service Miscellaneous Publication 1146.

LONG, R. W., and O. LAKELA. 1971. A flora of tropical Florida. University of Miami Press, Coral Gables.

LOOMAN, J. 1983. Distribution of plant species and vegetation types in relation to climate. Vegetatio 54: 17–25.

MATHER, J. R., and G. A. YOSHIOKA. 1968. The role of climate in the distribution of vegetation. Annals of the Association of American Geographers 54: 29–41.

MIDWESTERN REGIONAL CLIMATE CENTER. 2000. Climate summaries for the Midwest. Internet URL: ⟨http://mcc.sws.uiuc.edu/Summary/index.html⟩.

NARUHASHI, N. 1987. On the identity of Linnaean *Rubus parvifolius*, a small-leaved bramble from NE Asia and SE Australia. Journal of Phytogeography & Taxonomy 35: 3–12.

NATIONAL GERMPLASM RESOURCES LABORATORY—DATABASE MANAGEMENT UNIT. 2000. Germplasm Resources Information Network—National Plant Germplasm System database. Internet URL: ⟨http://www.ars-grin.gov/npgs⟩.

NORRIS, W. R., D. Q. LEWIS, M. P. WIDRLECHNER, J. D. THOMPSON, and R. O. POPE. 2001. Lessons from an inventory of the Ames, Iowa flora (1859–2000). Journal of the Iowa Academy of Science 108: 34–63.

OHWI, J. 1965. Flora of Japan. Smithsonian Institution, Washington, DC.

PANETTA, F. D. 1993. A system of assessing proposed plant introductions for weed potential. Plant Protection Quarterly 8: 10–14.

PANETTA, F. D., and N. D. MITCHELL. 1991a. Bioclimatic prediction of the potential distributions of some weed species prohibited entry to New Zealand. New Zealand Journal of Agricultural Research 34: 341–350.

PANETTA, F. D., and N. D. MITCHELL. 1991b. Homoclime analysis and the prediction of weediness. Weed Research 31: 273–284.

PARKER, I. M., and S. H. REICHARD. 1998. Critical issues in invasion biology for conservation science. Pages 283–305. *In* Conservation biology for the coming decade. P. L. Fiedler and P. M. Kareiva (eds.). Chapman and Hall, New York.

PIGOTT, C. D., and J. P. HUNTLEY. 1981. Factors controlling the distribution of *Tilia cordata* at the northern limit of its geographical range. III. Nature and cause of seed sterility. New Phytologist 87: 817–839.

PRIOR, J. C. 1991. Landforms of Iowa. University of Iowa Press, Iowa City.

QUAMME, H. A., R. E. C. LAYNE, and W. G. RONALD. 1982. Relationship of supercooling to cold hardiness and the northern distribution of several cultivated and native *Prunus* species and hybrids. Canadian Journal of Plant Science 62: 137–148.

REICHARD, S. H., and C. W. HAMILTON. 1997. Predicting invasions of woody plants introduced into North America. Conservation Biology 11: 193–203.

SAPOZHNIKOVA, S. A. (ed.) 1964. Agroklimaticheskii atlas Ukrainskoi SSR. Izdatel'stvo Urozhai, Kiev.

SCOTT, J. K., and F. D. PANETTA. 1993. Predicting the Australian weed status of southern African plants. Journal of Biogeography 20: 87–93.

SHAO, G., and P. N. HALPIN. 1995. Climatic controls of eastern North American coastal tree and shrub distributions. Journal of Biogeography 22: 1083–1089.

SKRE, O. 1979. The regional distribution of vascular plants in Scandinavia with requirements for high summer temperatures. Norwegian Journal of Botany 26: 295–318.

SOWELL, J. B. 1985. A predictive model relating North American plant formations and climate. Vegetatio 60: 103–111.

STEINHAUSER, F. (ed.) 1970. Climatic atlas of Europe. Volume 1. Maps of mean temperature and precipitation. WMO, UNESCO, Geneva. 28 maps.

STEINHAUSER, F. (ed.) 1979. Climatic atlas of North and Central America. Volume 1. Maps of mean temperature and precipitation. WMO, UNESCO, Geneva. 28 maps.

STEPHENSON, N. L. 1990. Climatic control of vegetation distribution: The role of the water balance. American Naturalist 135: 649–670.

STEYERMARK, J. A. 1963. Flora of Missouri. Iowa State University Press, Ames.

STRAUSBAUGH, P. D., and E. L. CORE. 1978. Flora of West Virginia. 2nd ed. Seneca Books, Grantsville, WV.

SWINK, F., and G. WILHELM. 1994. Plants of the Chicago region. 4th ed. Indiana Academy of Science, Indianapolis.

THOMPSON, R. S., K. H. ANDERSON, and P. J. BARTLEIN. 2000. Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America. USGS Professional Paper 1650, 2 volumes.

THRAN, P., and S. BROCKHUIZEN. 1965. Agro-ecological atlas of cereal growing in Europe. PUDOC, Wageningen.

TUTIN, T. G., V. H. HEYWOOD, N. A. BURGES, D. M. MOORE, D. H. VALENTINE, S. M. WALTERS, and D. A. WEBB. (eds.) 1964–1980. Flora Europaea. Cambridge University Press, Cambridge. 5 volumes.

VAN DER LINDEN, P. J., and D. R. FARRAR. 1984. Forest and shade trees of Iowa. Iowa State University Press, Ames.

VOIKOV MAIN GEOPHYSICAL OBSERVATORY. 1981. Climatic atlas of Asia. Volume 1. Maps of mean temperature and precipitation. WMO, Geneva, UNESCO, Paris, and Goscomgidromot USSR, Moscow. 28 maps.

WHERRY, E. T., J. M. FOGG, JR., and H. A. WAHL. 1979. Atlas of the flora of Pennsylvania. Morris Arboretum, Philadelphia.

WIDRLECHNER, M. P. 1992. Is eastern Europe a useful source of new

landscape plants for the Midwest? Combined Proceedings of the International Plant Propagators' Society 42: 451–455.

WIDRLECHNER, M. P. 1994. Environmental analogs in the search for stress-tolerant landscape plants. Journal of Arboriculture 20: 114–119.

WIDRLECHNER, M. P. 1999. A zone map for mean annual moisture balance in the north central United States. Landscape Plant News 10(2): 10–14.

WIDRLECHNER, M. P., E. R. HASSELKUS, D. E. HERMAN, J. K. ILES, J. C. PAIR, E. T. PAPAROZZI, R. E. SCHUTZKI, and D. K. WILDUNG. 1992. Performance of landscape plants from Yugoslavia in the north central United States. Journal of Environmental Horticulture 10: 192–198.

WIDRLECHNER, M. P., J. B. HEBEL, D. E. HERMAN, J. K. ILES, G. J. KLING, A. P. OVROM, J. C. PAIR, E. T. PAPAROZZI, S. R. POPPE, N. ROSE, R. E. SCHUTZKI, C. TUBESING, and D. K. WILDUNG. 1998. Performance of landscape plants from northern Japan in the north central United States. Journal of Environmental Horticulture 16: 27–32.

WIERSEMA, J. H. 1995. Taxonomic information on cultivated plants in the USDA/ARS Germplasm Resources Information Network (GRIN). Acta Horticulturae 413: 109–115.

WILLIAMSON, M. 1993. Invaders, weeds and the risk from genetically manipulated organisms. Experientia 49: 219–224.

WILSON, B. L. 1992. Checklist of the vascular flora of Page County, Iowa. Journal of the Iowa Academy of Science 99: 23–33.

WOODWARD, F. I., and B. G. WILLIAMS. 1987. Climate and plant distribution at global and local scales. Vegetatio 69: 189–197.

WUNDERLIN, R. P. 1982. Guide to the vascular plants of central Florida. University Presses of Florida, Tampa.